Testing Metrics Development – Application Dependent

October 19, 2011

Benjamin L. Schenkman
Sandia National Laboratories

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Battery Testing Background

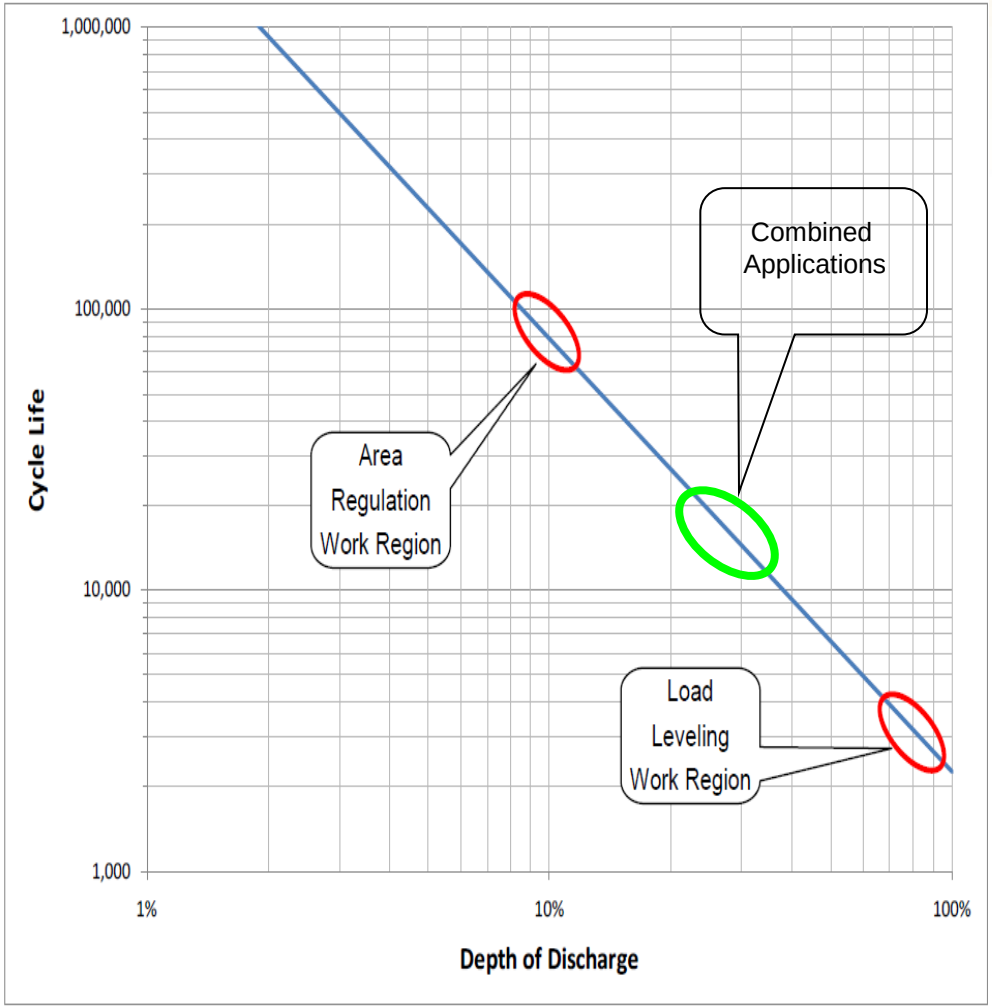
- **Constant charge and discharge rate at various depth of discharges**
- **Capacity, Round Trip Efficiency, Self-Discharge, etc.**
- **Great for comparison of various technologies and benchmarking**

Sandia National Laboratories

Battery Testing Problem

- Battery systems in the field are not constantly charged and discharged

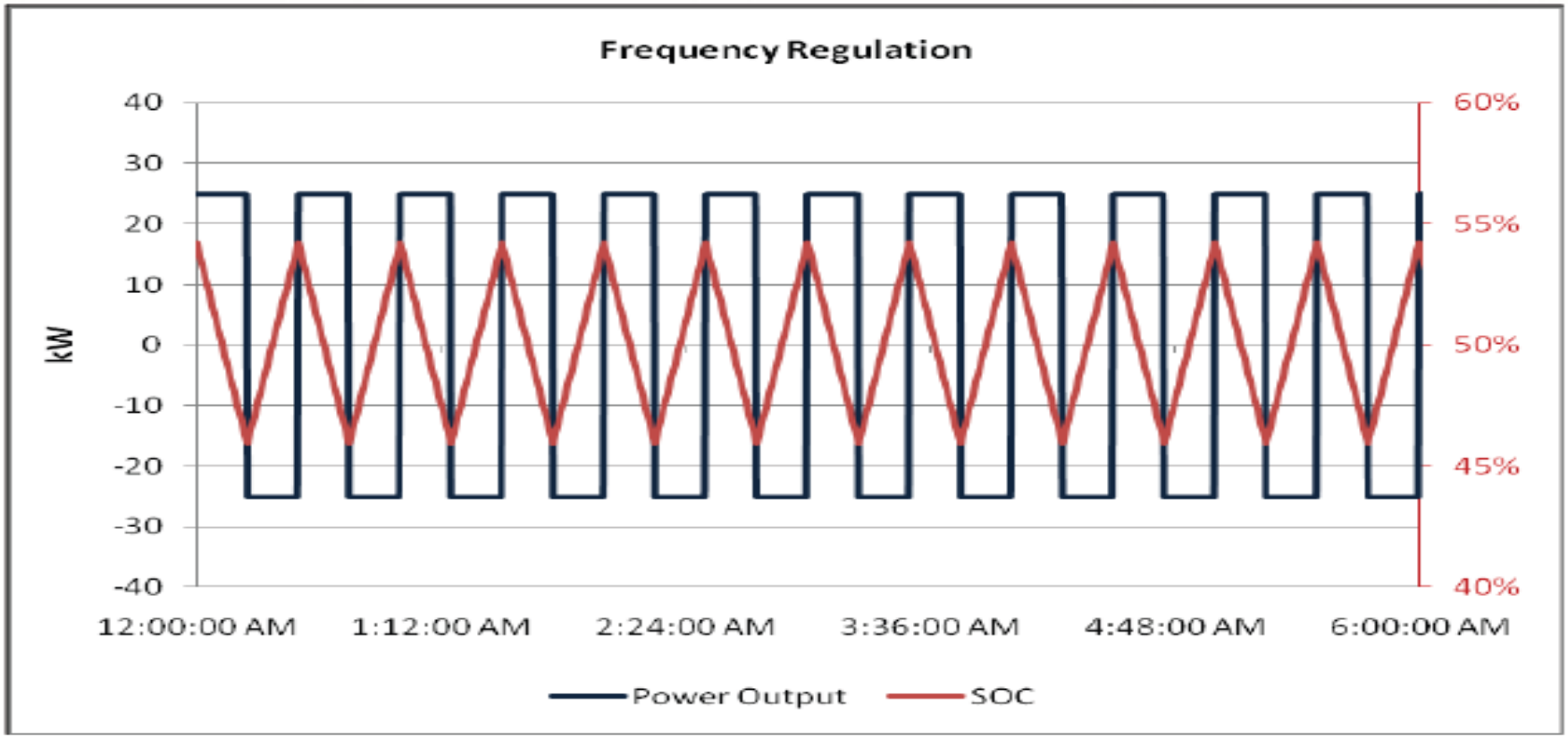
- Testing today is not driven by intended application(s)



Picture provided by KEMA

Sandia National Laboratories

Battery Testing Problem



Picture provided by KEMA

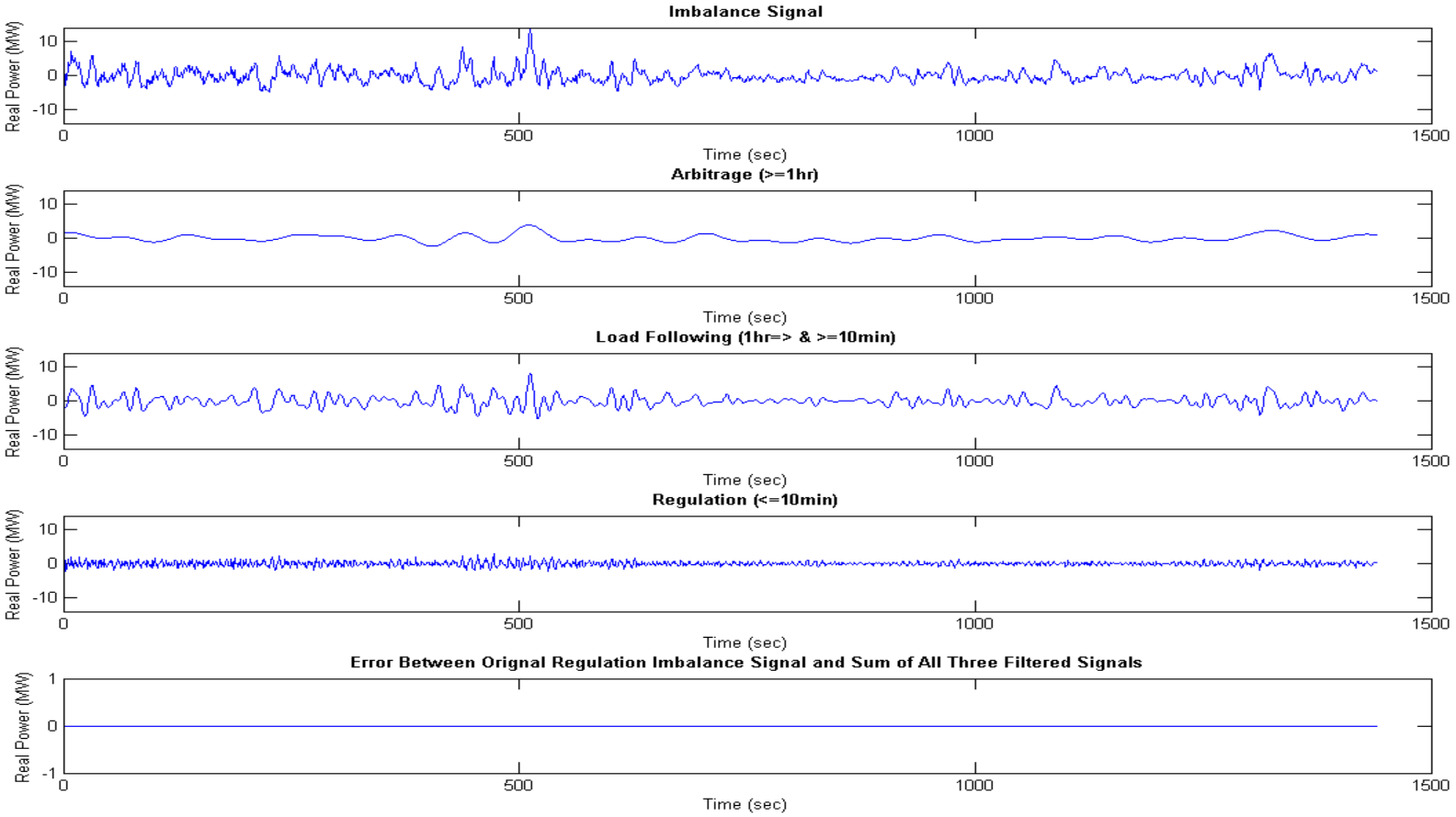
Sandia National Laboratories

Proposed New Battery Test Methodology

- **Gather information regarding application(s)**
- **Develop and characterize required power delivery or absorption for energy storage system**
- **Using Auto Regression, create a discrete transfer function that represents the required power signal and scale for single cell**
- **Use random numbers such as “Gaussian White Noise” to drive a waveform generator that will produce a similar, but not the same, required power signal with all the “wiggles”**

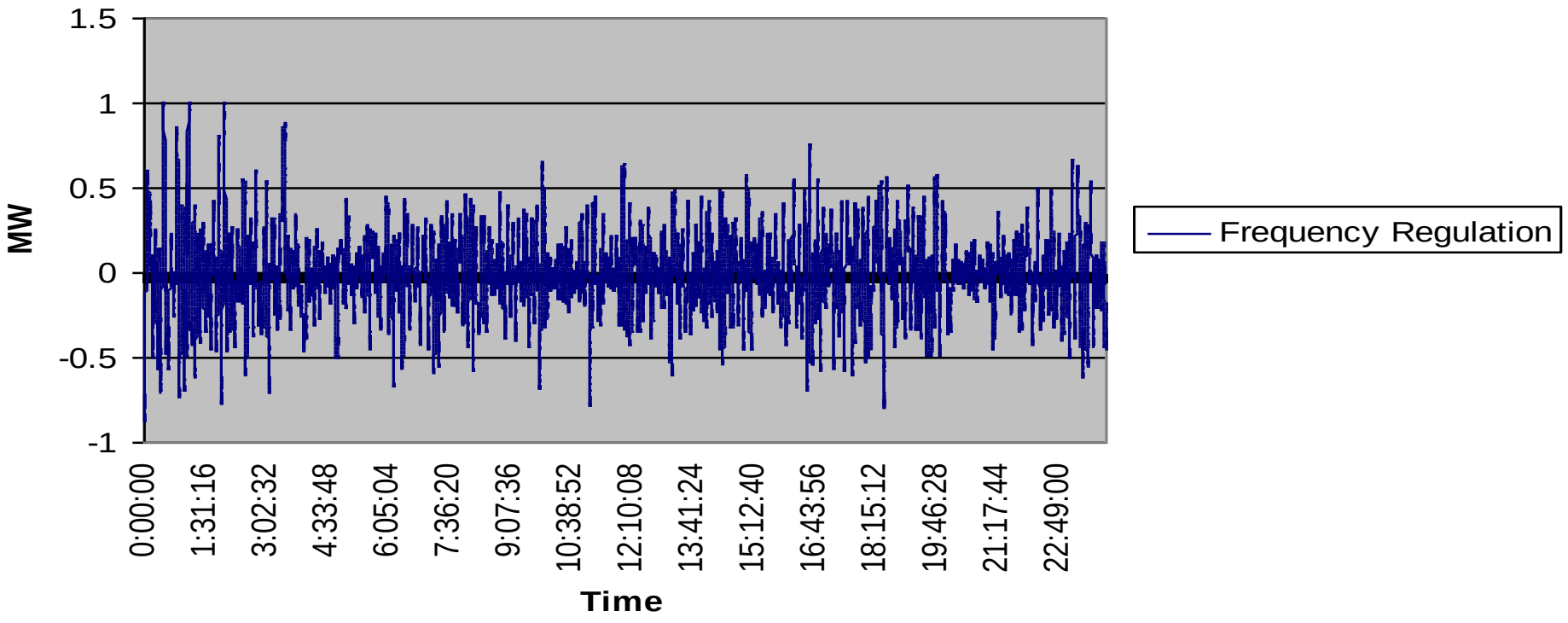
Sandia National Laboratories

Application Information Gathering



Sandia National Laboratories

Application Information Gathering



http://www.pjm.com/markets-and-operations/ancillary-services/mkt-based-regualtion.aspx

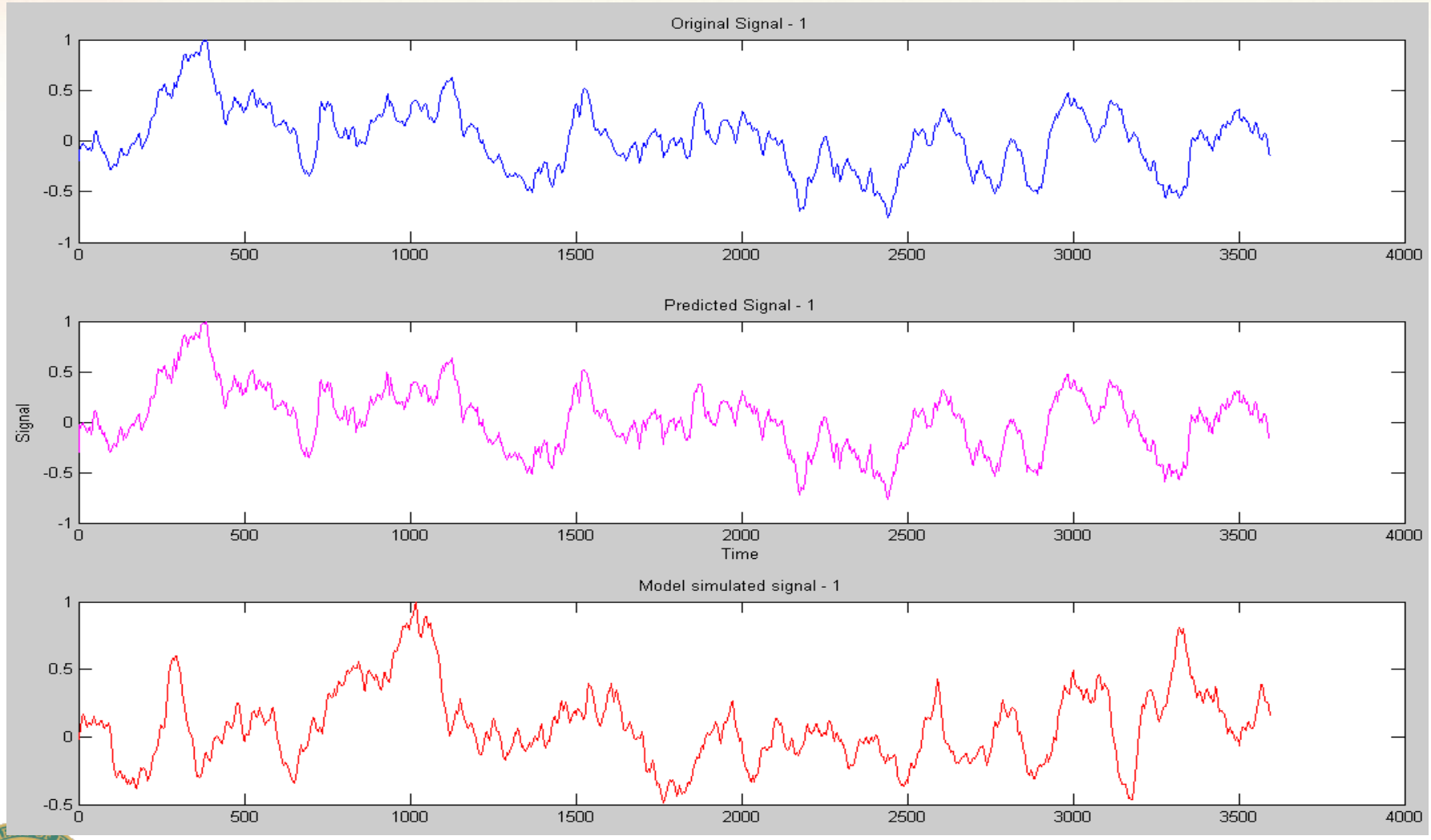
Sandia National Laboratories

Battery Storage Signal Characterization

- **Model Equation**
  - $z(kT) = a_1 z((k-1)T) + a_2 z((k-2)T) + a_3 z((k-3)T) + a_4 k((k-4)T + v(kT)$
- **Prediction Based on Model**
  - $\check{z}(kT) = a_1 z((k-1)T) + a_2 z((k-2)T) + a_3 z((k-3)T) + a_4 k((k-4)T + v(kT)$
- **Prediction Error**
  - $e(kT) = z(kT) - \check{z}(kT)$
- **Performance Metric**
  - $J = \|e\|^2 / \|z\|^2$
- **v(kT) is noise input taken as zero mean Gaussian white noise with variance given by the AR modeling calculations**

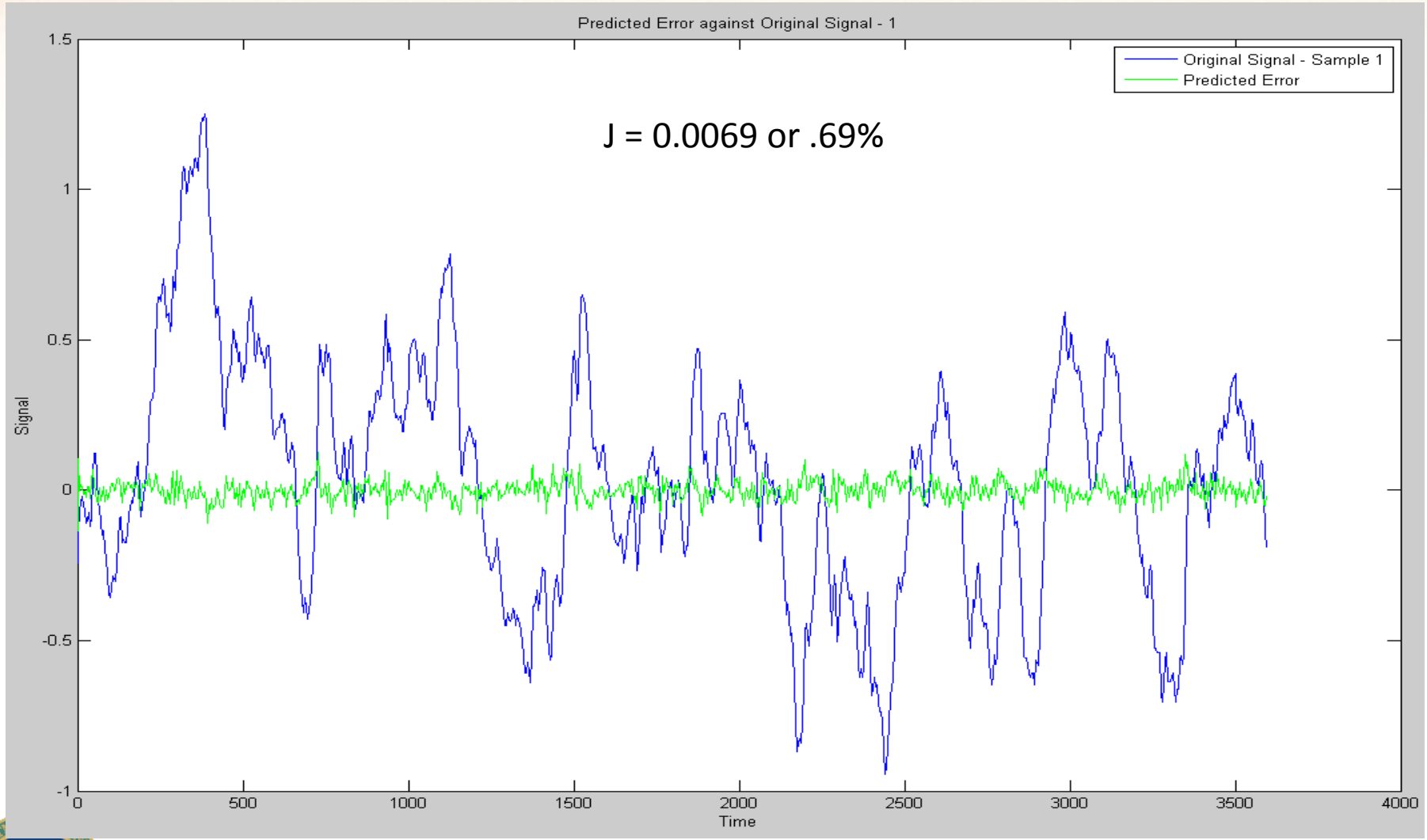
Sandia National Laboratories

Results of a Sample



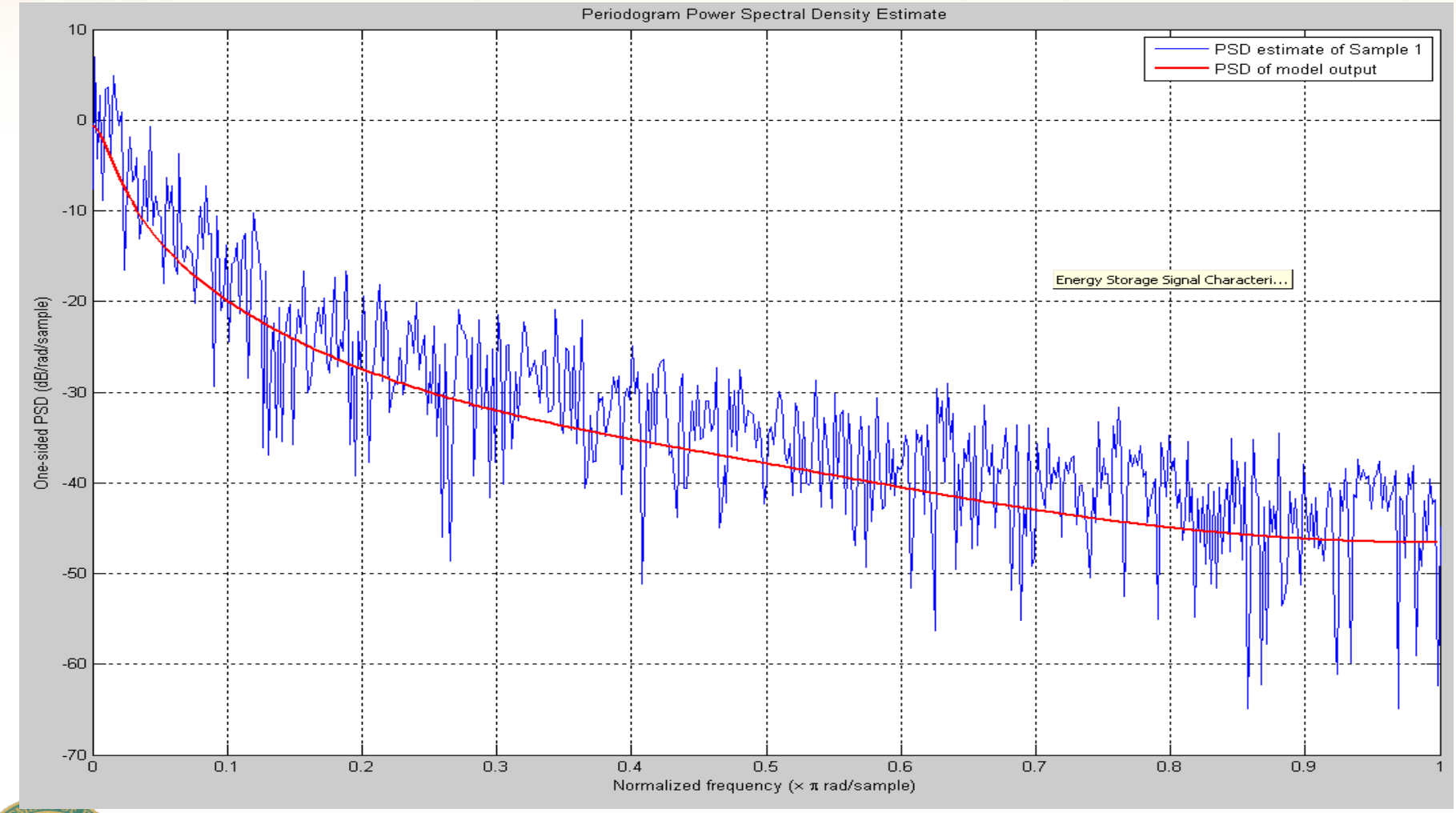
Sandia National Laboratories

Results of a Sample



Sandia National Laboratories

Results of a Sample



Sandia National Laboratories

Summary

- Performed signal characterization for the application of frequency response
- Used actual data from PJM in hourly samples
- Performed Auto Regression (AR) to characterize the signal
- Developed a random signal from the AR and compared to original signal
- Started working on creating a discrete transfer function that would represent the power electronics between the batteries and the utility through a different project

Sandia National Laboratories

Future Tasks

- Compare 1 year of frequency regulation data versus a small subset of data from heavy/light summer/winter loads
- Develop signal for applications that be combined to benefit from multiple revenue streams
- Test AR generated signal versus traditional testing
- Create testing standards based on results
- Complete discrete transfer function representing 3-phase power electronics between battery and utility

Sandia National Laboratories

Acknowledgements

- Dr. Imre Gyuk

  U.S. Department of Energy, Energy Storage Research

- Dr. Pramod Khargonekar

  Florida State University

Sandia National Laboratories